Heavy-Flavor Measurements with the PHENIX Experiment at RHIC

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Outline

- Open charm physics
- The PHENIX experiment
- Open charm measurements
  - single electrons from charm decays ($c \rightarrow D \rightarrow e + X$)
  - in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV and 200 GeV
- Charmonium physics
- J/Ψ production measurements
  - $J/\Psi \rightarrow \mu^+ \mu^-$, $e^+ e^-$ in p+p and Au+Au at $\sqrt{s_{NN}} = 200$ GeV

Open charm physics

- charm production in heavy-ion collisions
  - production mainly via gg fusion in earliest stage of collision

  ➡ sensitive to initial gluon density

  - additional thermal production at very high temperature $\rightarrow$ enhancement?

  ➡ sensitive to initial temperature

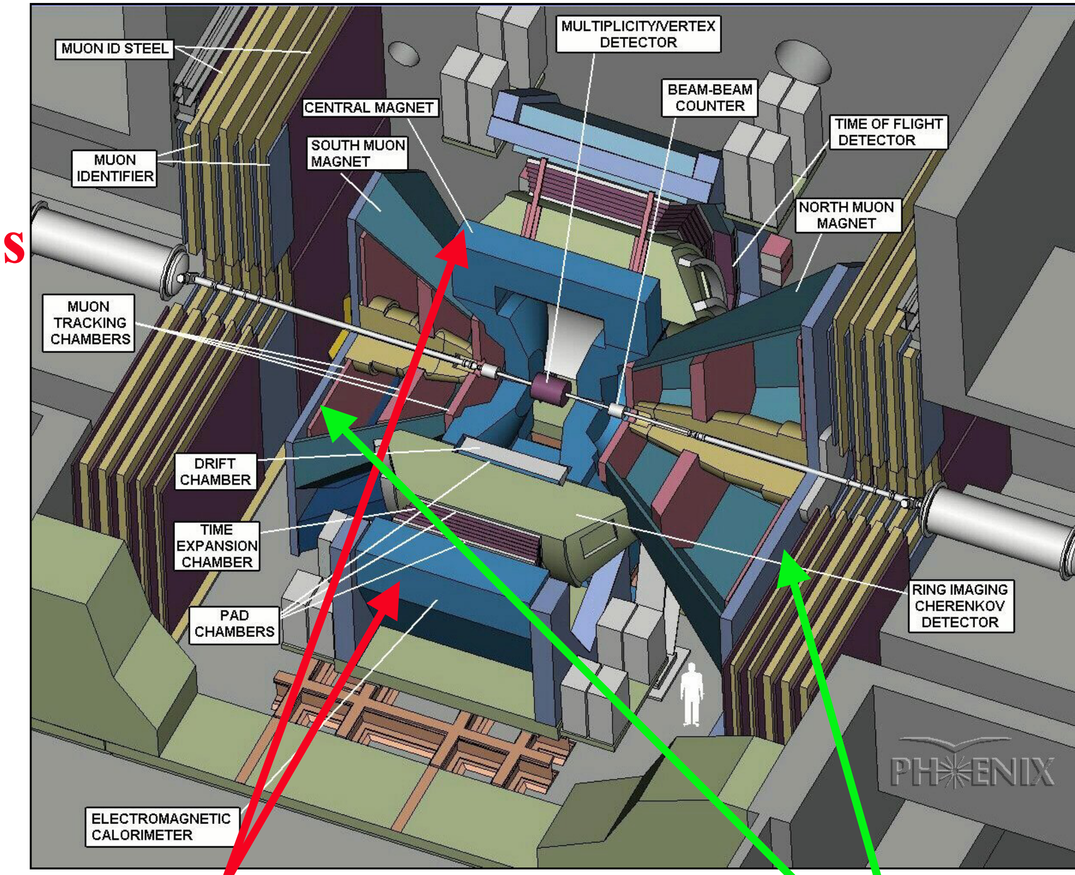
- propagation through dense (deconfined?) medium
  - energy loss by gluon radiation? $\rightarrow$ softening of D-meson spectra?

  ➡ sensitive to state of nuclear medium

- how to measure open charm
  - direct reconstruction of charm decays (e.g. $D^0 \rightarrow K^- \pi^+$)
    – ideal but very challenging
  - determine contribution of semi leptonic charm decays (e.g. $D^0 \rightarrow K^- l^+ \nu_e$) to single lepton and lepton pair spectra
    – alternative, indirect approach

The PHENIX experiment

- only RHIC experiment optimized for lepton measurements
- electrons: two central arms
  - electron measurement in range:
    $|\eta| \leq 0.35$
    $p \geq 0.2$ GeV/c
- muons: two forward arms
  - muon measurement in range:
    $1.2 < |\eta| < 2.4$
    $p \geq 2$ GeV/c

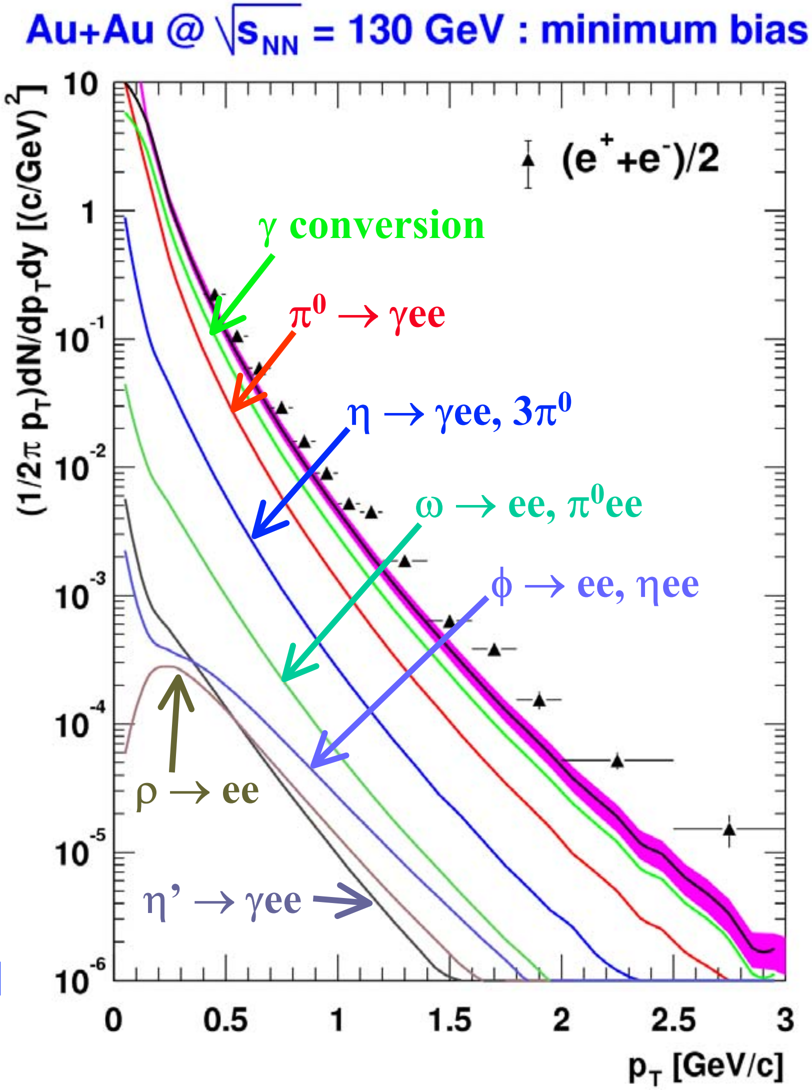


Two central electron/photon/hadron spectrometers

Two forward muon spectrometers

Inferring charm production: cocktail method

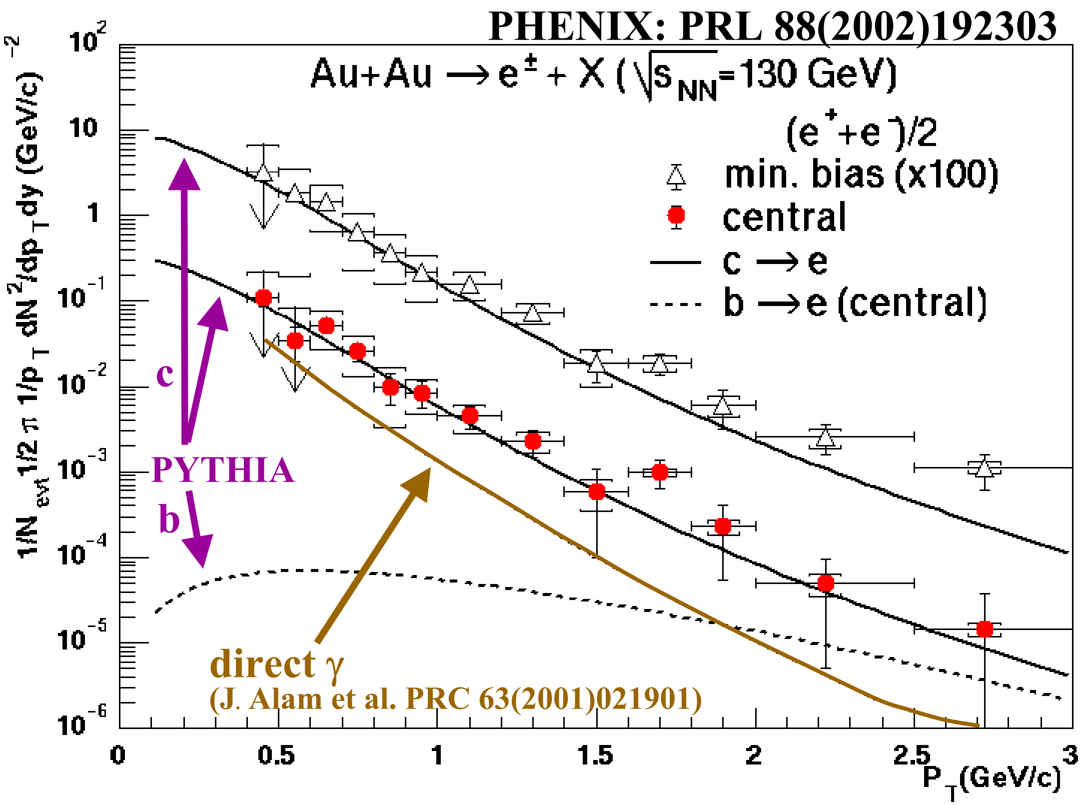
- inclusive $e^{\pm}$ spectra from Au+Au at 130 GeV
- use available data to establish "cocktail" of $e^{\pm}$ sources
  - dominated by measured π^0 and photon conversions
- excess above cocktail
  - increasing with p_T
  - expected from charm decays
- subtract cocktail from data
- attribute excess to open charm



PHENIX: PRL 88(2002)192303

Electron spectra from Au+Au at 130 GeV

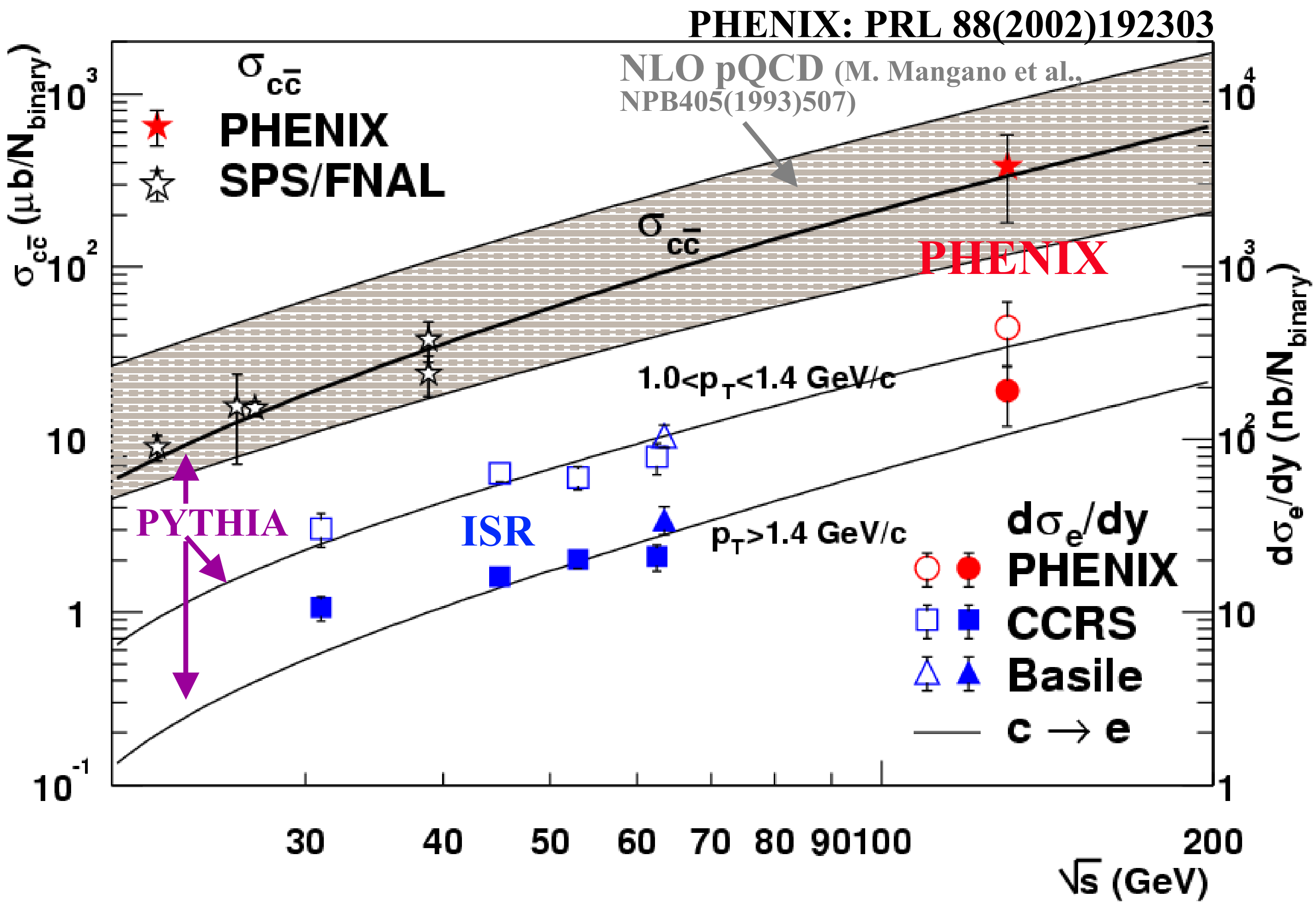
- compare excess $e^{\pm}$ spectra with PYTHIA open charm calculations
  - PYTHIA tuned to fit SPS, FNAL, ISR data ($\sqrt{s}$<63 GeV)
  - scale to Au+Au using the number of binary collisions
- reasonable agreement in min. bias AND central collisions between data and PYTHIA



- corresponding charm cross section per binary collision from data

$$\sigma_{c\bar{c}}^{0-10\%} = 380 \pm 60 \pm 200 \mu b \qquad \sigma_{c\bar{c}}^{0-92\%} = 420 \pm 33 \pm 250 \mu b$$

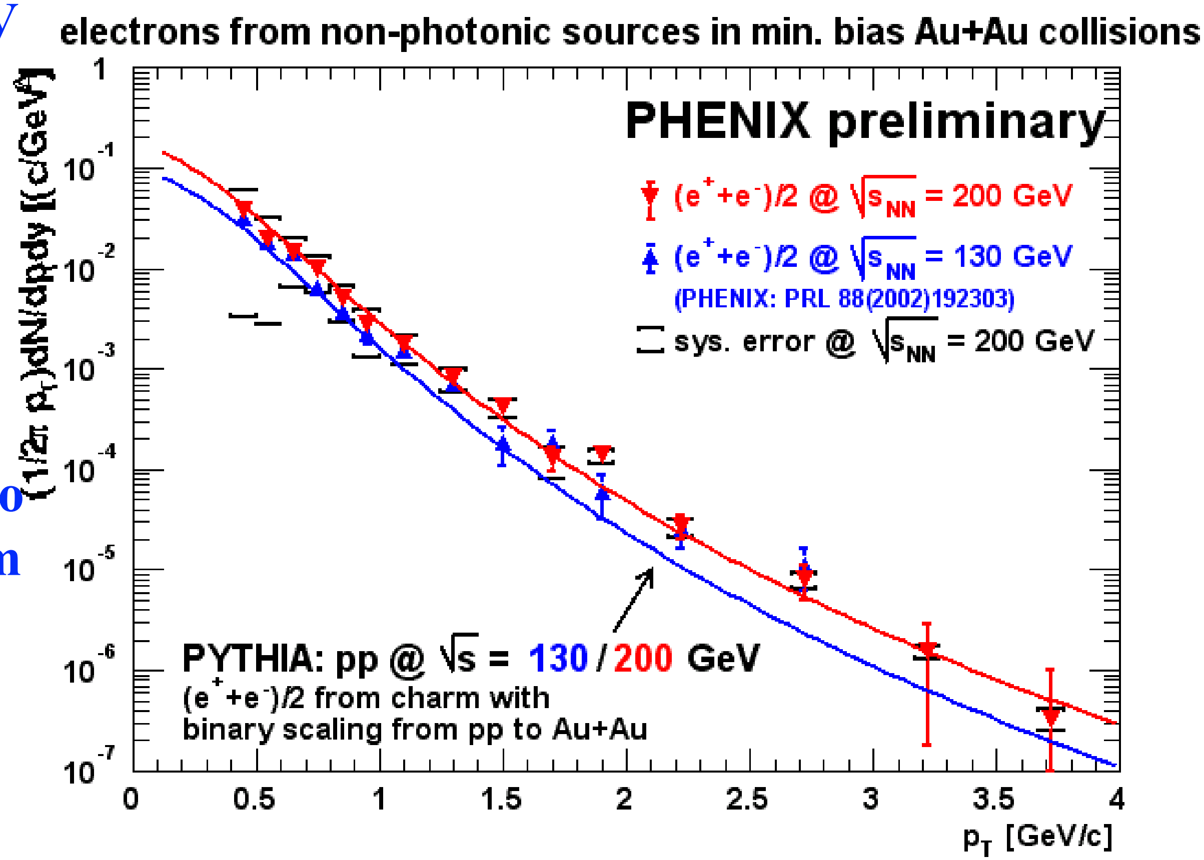
Systematic trends with collision energy



- assuming binary collision scaling, PHENIX data are consistent with the $\sqrt{s}$ systematics (within large uncertainties)

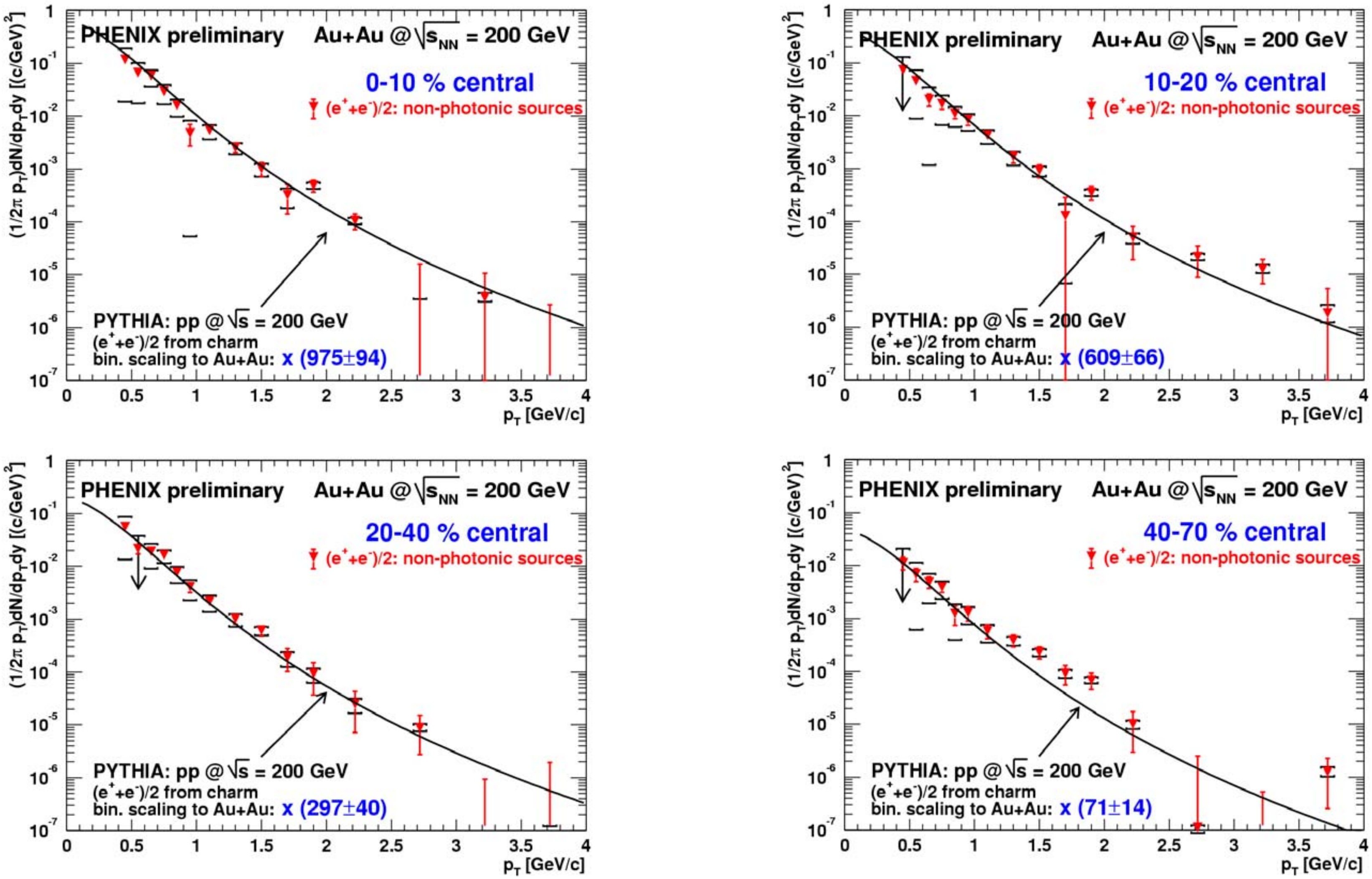
Inferring charm production: converter method

- Au+Au at $\sqrt{s_{NN}}$ = 200 GeV
- measure the $e^{\pm}$ spectrum from photonic sources (γ, π^0, η, …) by adding a photon converter to PHENIX
- subtract the photonic spectrum from the total to produce $e^{\pm}$ spectrum from non-photonic sources
- non-photonic $e^{\pm}$ yield at 200 GeV
  - larger than at 130 GeV
  - consistent with PYTHIA calculation, assuming binary scaling: $\sigma_{c\bar{c}}$(130 GeV) = 330 μb and $\sigma_{c\bar{c}}$(200 GeV) = 650 μb



- large systematic uncertainty due to material thickness without converter (to be reduced in final result)

Centrality dependence

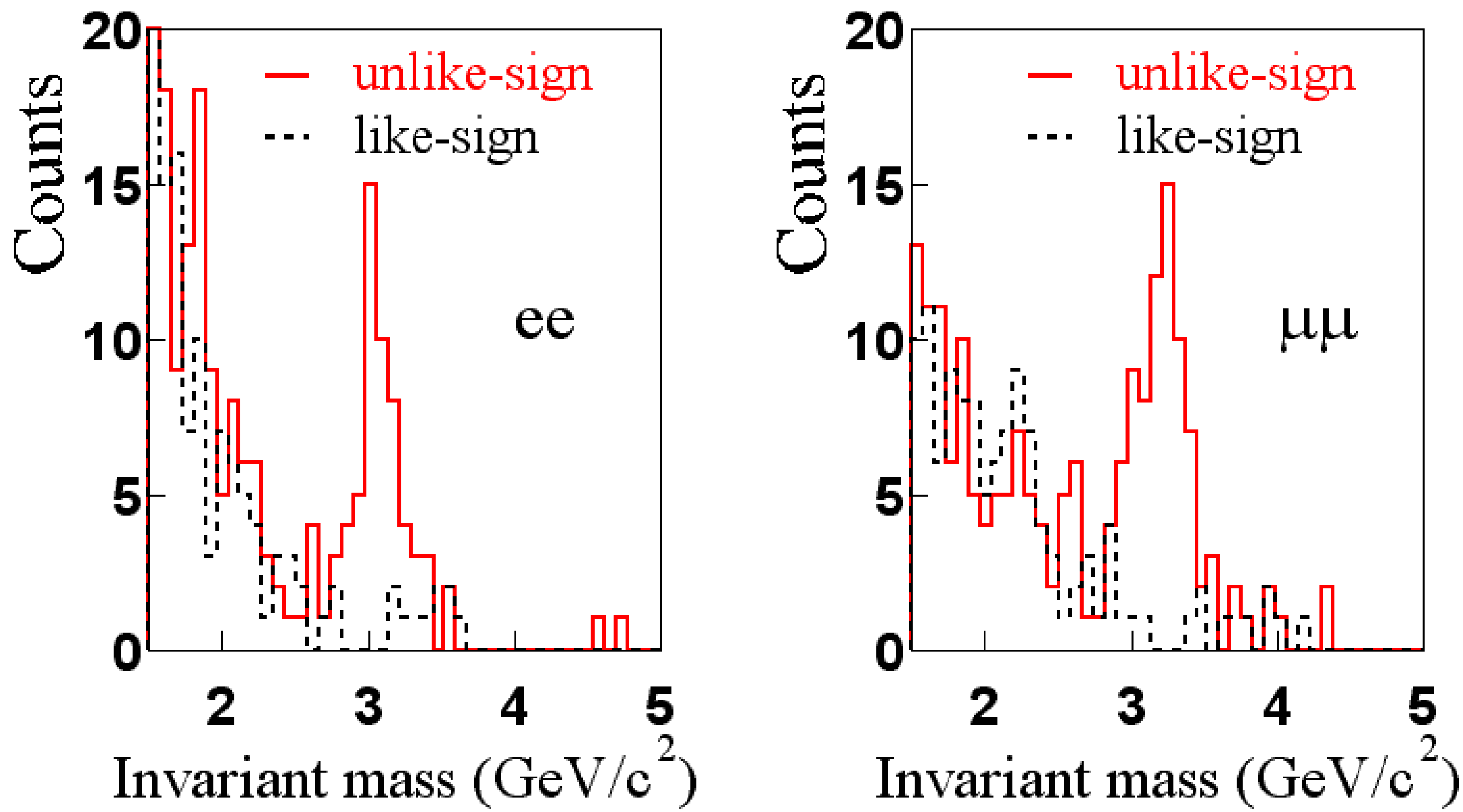


- **PHENIX data are consistent with the PYTHIA charm spectrum scaled by the number of binary collisions in all centrality bins!**

Charmonium (J/Ψ) physics

- interest in high energy heavy-ion collisions
  - possible signature of the deconfinement phase transition
  - J/Ψ yield can be
    - suppressed, because of Debye screening of the attractive potential between c and $\bar{c}$ in the deconfined medium
    - enhanced, because of $c\bar{c}$ coalescence as the medium cools
- important to measure J/Ψ in p+p and d+Au to separate "normal" nuclear effects
  - shadowing
  - nuclear absorption in cold matter
- J/Ψ measurements in leptonic decay channels
  - $J/\Psi \rightarrow e^+ e^-$ and $J/\Psi \rightarrow \mu^+ \mu^-$ in p+p at $\sqrt{s} = 200$ GeV
  - $J/\Psi \rightarrow e^+ e^-$ in Au+Au at $\sqrt{s_{NN}} = 200$ GeV

J/Ψ production: establishing a p+p baseline

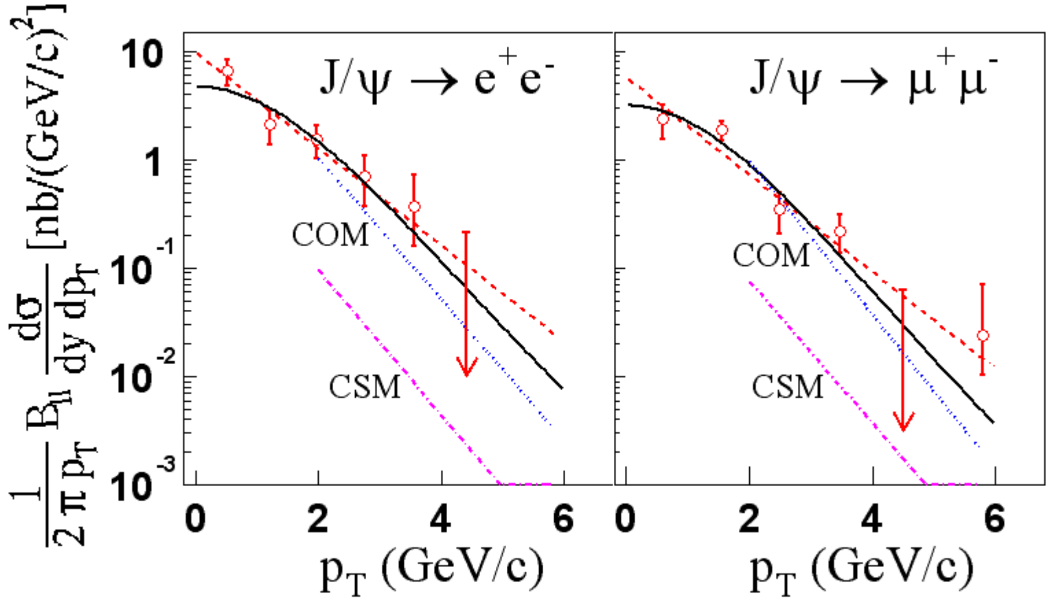


- p+p collisions at √s = 200 GeV
- clear J/Ψ signals seen in both central and muon arms
- resolution in agreement with expectations

J/Ψ in p+p: kinematic distributions

- **transverse momentum**
  - **combination of electron and muon results**
  - **phenomenological and exponential fits**

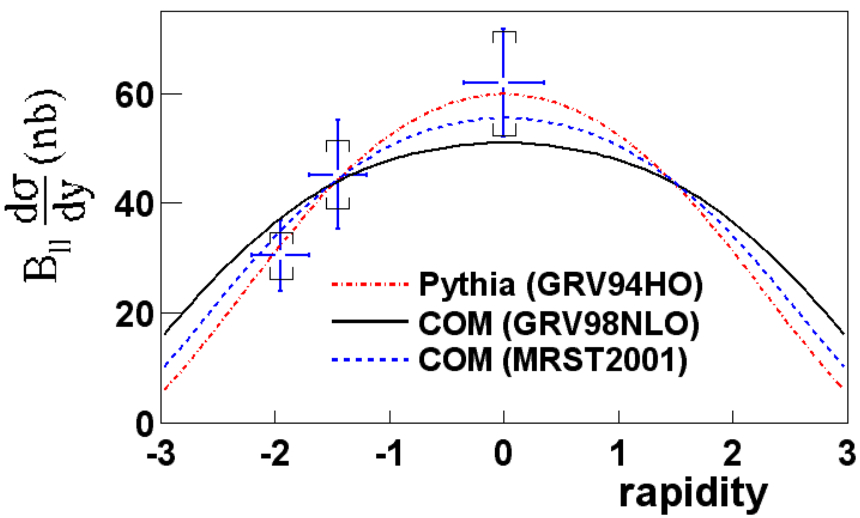
$\langle p_T \rangle$ = 1.80 ± 0.23 (stat) ± 0.16 (sys) GeV/c



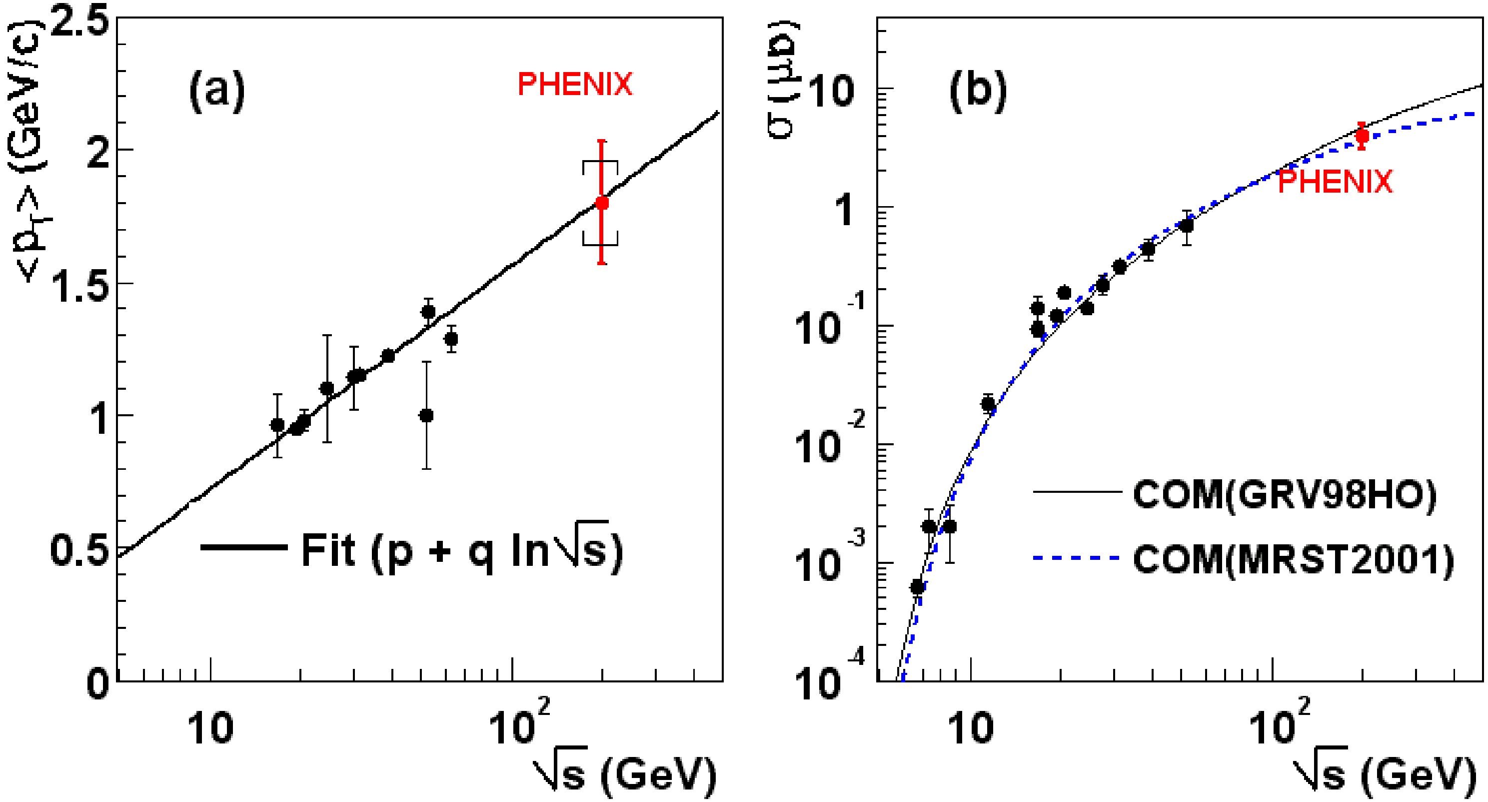
  - **Color Singlet Model underpredicts the cross section**
  - **Color Octet Model agrees reasonably with data**
- **rapidity**
  - **integrated cross section**

3.98 ± 0.62 (stat) ± 0.56 (sys) ± 0.40 (abs) μb

  - **estimated B decay feed down contribution:** < 4% (at 200 GeV)



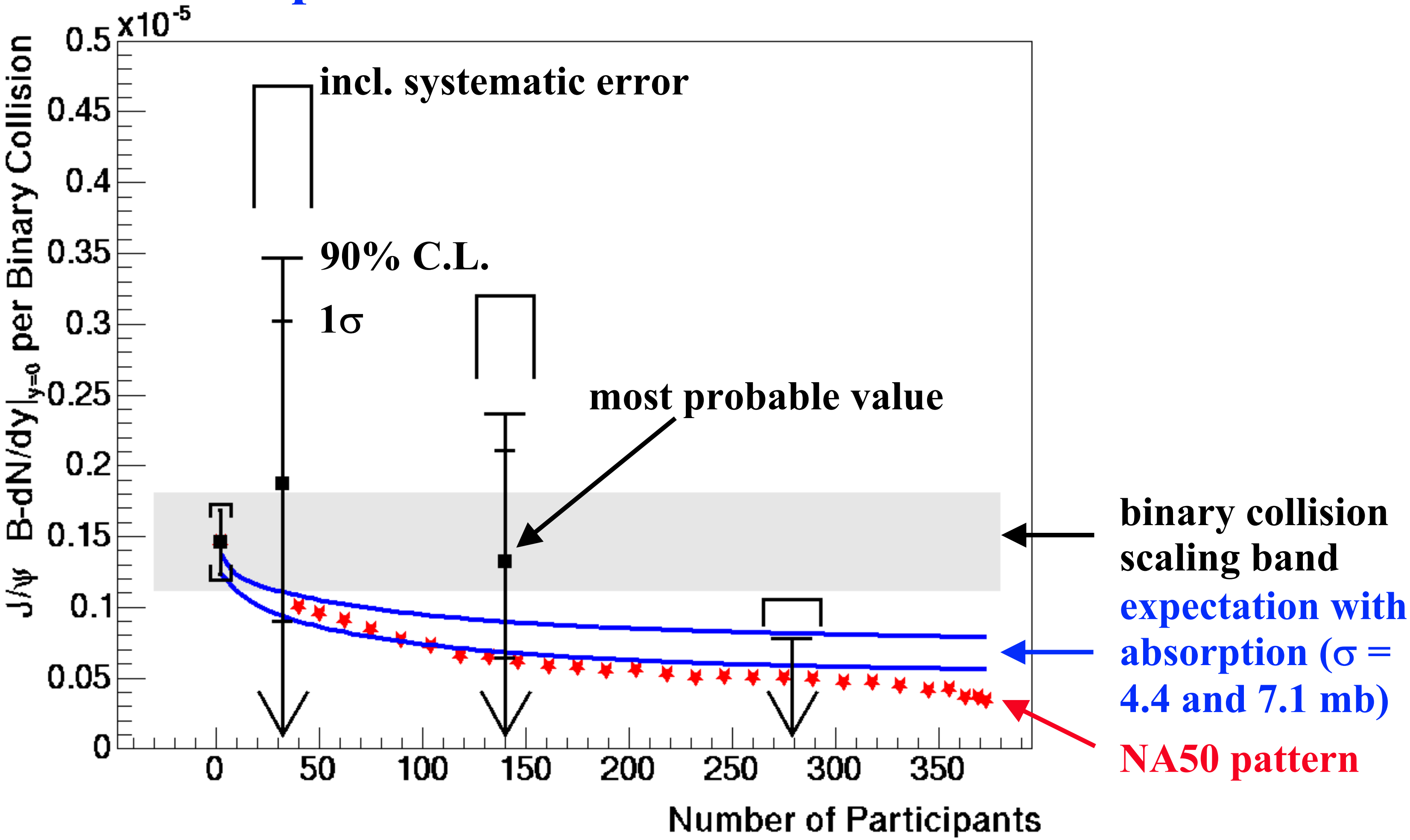
Comparison with other experiments



- phenomenological fit for average p_T: $p = 0.531$, $q = 0.188$
- cross section well described by Color Octet Model

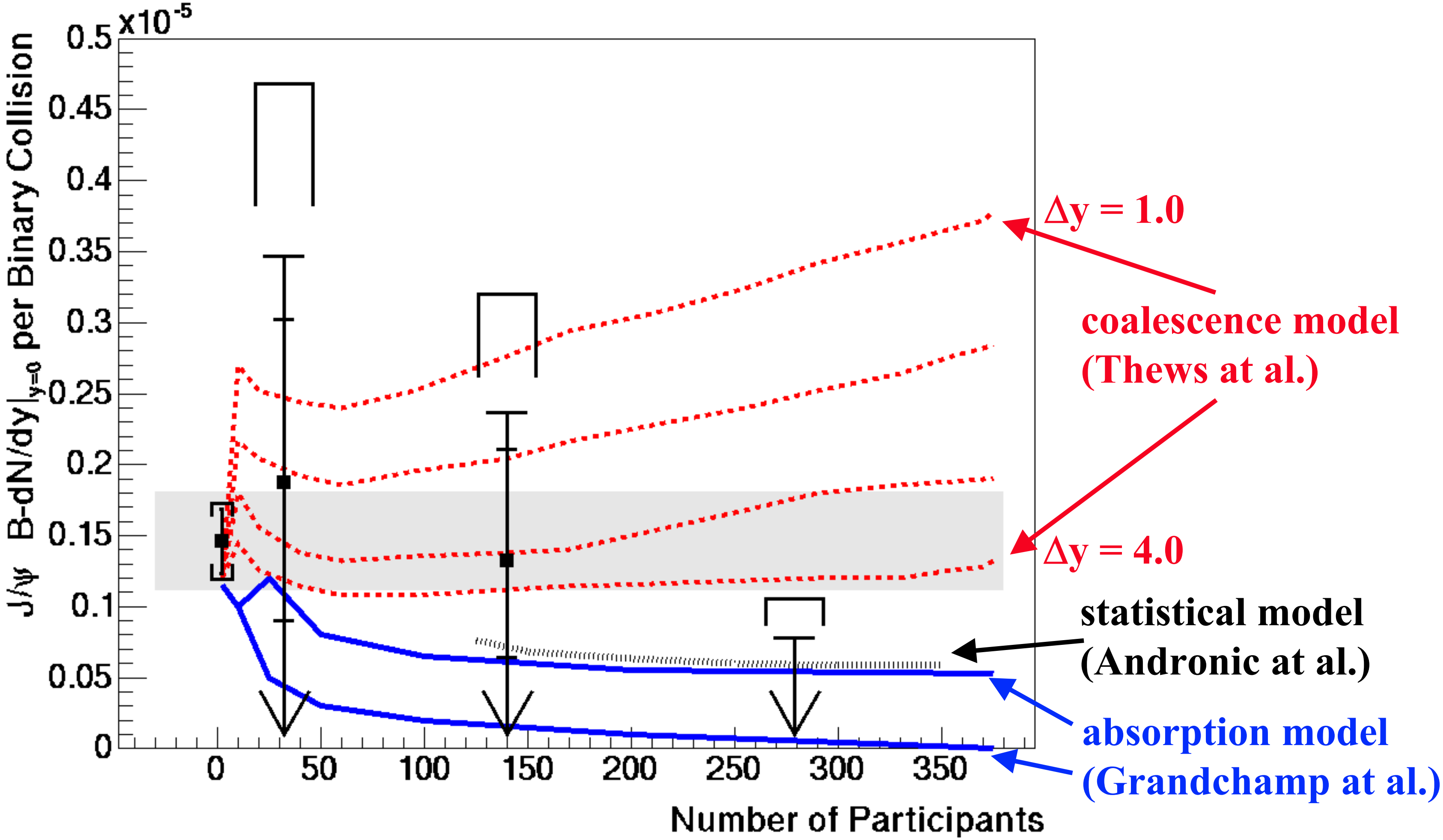
$J/\Psi \to e^+e^-$ in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

- statistics are poor



- J/Ψ absorption pattern as observed at SPS (NA50: PLB477(2000)28) normalized to PHENIX p+p measurement

Model comparisons



- models that predict enhancement relative to binary collision scaling are disfavored
- no discrimination between models that lead to suppression

Summary

- open charm production at RHIC
  - consistent with binary collision scaling of PYTHIA calculation
  - charm enhancement by factor ~3 inferred by NA50 at SPS
    - no large effect observed at RHIC
  - suppression of high p_T hadrons by factor ~3-5 observed at RHIC
    - no large effect observed in $e^{\pm}$ from charm decays
    - possible explanations:
      - dead cone effect (Y.L. Dokshitzer, D.E. Kharzeev PLB 519(2001)199)
      - hydrodynamic flow of charm (S. Batsouli et al. PLB 557(2003)26)
      - …
- J/Ψ production at RHIC
  - baseline established in p+p collisions
    - results follow smoothly upon lower $\sqrt{s}$ data and phenomenological extrapolations
  - present data disfavor strong enhancement scenarios in Au+Au

Outlook

- open charm production at RHIC
  - significant reduction of sys. errors possible in $e^{\pm}$ analysis
  - replace PYTHIA reference by measurement from p+p
  - independent cross checks: $\mu^{\pm}$ data and lepton-pair data
  - d+Au measurement done to establish "cold matter" reference
- J/Ψ production at RHIC
  - d+Au measurement done to study "normal" nuclear effects
- high statistics Au+Au data are needed!